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ABSTRACT

This document outlines the use of machine-scorable open-ended questions for the evaluation of Physics 30 in Alberta. Contents include: (1) an introduction to the questions; (2) sample instruction sheet; (3) fifteen sample items; (4) item information including the key, difficulty, and source of each item; (5) solutions to items having multiple answers; (6) an answer sheet with solutions; and (7) a blank answer sheet. (YP)

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Diploma Examinations Program

Physics 30 Program
Machine-Scorable Open-Ended Questions

Unit 2: Electric and Magnetic Forces

Students First !

Student Evaluation and Records

Alberta EDUCATION

September 1989

SE 051 210

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PREFACE

This document outlines the use of machine-scorable open-ended questions in the evaluation of Physics 30. It is primarily designed for use by classroom teachers of Physics 30, though it can be modified for use by teachers of Physics 10 and Physics 20. The sample items provided were originally asked in multiple-choice form on Grade 12 Diploma Examinations.

The use of machine-scorable open-ended questions is being considered for the 1991 series of Diploma Examinations in Physics 30, and such questions are being introduced on the 1990 field tests. Students writing these field tests should be made familiar with the use of this item format.

The document can also be used for professional inservice at the school or jurisdiction level. In this case, supplementary materials suitable to local needs could be added to the basic foundation provided here.

To obtain further copies, or to make comments about this document, you are invited to contact:

Jack Edwards
Examination Manager, Physics 30
Student Evaluation and Records Branch
Alberta Education
Box 43, Devonian Building
11160 Jasper Avenue
Edmonton, Alberta
T5K 0L2

427-2948 Fax: 422-4200

SEPTEMBER 1989

INTRODUCTION TO MACHINE-SCORABLE OPEN-ENDED ITEMS

It is now possible to have students derive the answer to an item and record the answer in a machine-readable form. Final answers can be expressed as a single number or as a sequence of numbers. This item format can be used as an alternative to multiple-choice, to sequencing, or to matching formats. Alberta Education uses the following guidelines for the construction of machine-scorable open-ended items:

- Solutions to machine-scorable open-ended items should be short and involve no more than one or two steps.
- All legitimate methods of solving a problem should lead to numerical answers that are marked correct.
- In general, each item should have the same weighting as a multiple-choice item.

Compared with multiple-choice items there are the following benefits:

- The chances of a student guessing an answer correctly is essentially reduced to zero.
- Answer verification methods are eliminated as students cannot work backwards from the alternatives provided.
- Students cannot determine the correct answer by eliminating the other distractors.
- Students cannot obtain additional clues from the list of possible responses presented.
- Machine-scorable open-ended items individually discriminate very well between strong and weak students at all difficulty levels.
- When these items are included on a test, the test as a whole will be more reliable in ranking the students from strongest to weakest.

However, the following limitations still apply:

- The effectiveness of this type of item has not yet been tested for subjects other than mathematics.
- Answer fields suitable for this type of Physics 30 item may be too complex for use.

Alberta Education has used machine-scorable open-ended questions successfully since January 1989 in its Mathematics 30 Diploma Examinations. The mathematics questions used a four space answer field, accommodating numbers between 0.1 and 999.9. All input numbers were presumed exact, and all numerical answers were required to be rounded to the nearest tenth. A standardized rounding instruction had to be given. Students were told to keep their calculators running for the whole item. When this instruction was given, multiple answers were eliminated.

In introducing machine-scorable open-ended questions to Physics 30 there are four main problems:

- Physics questions do not have answers that limit to the numerical range from 0.1 to 999.9. Allowance must be made for the use of scientific notation and metric prefixes.
  Possible solution: For numerical answers between 0.01 and 99.99 SI base units, there are no difficulties if the decimal is placed between the second and the third columns of the answer field. For numerical answers between 0.01 and 99.99 SI base units, there are no difficulties. We will use the prefixes *kilo*, *centi*, and *milli* freely, and will attach them to any SI base unit. The prefixes *mega* and *nano* will be restricted to common usages such as megahertz (MHz) and nanometre (nm). No other prefixes will be used in machine-scorable open-ended questions. We will express other large and small numbers in scientific notation, and will ask for either the numerical factor or the exponent. To allow for three digit accuracy in the numerical factor, the decimal point is placed between the second and the third columns of the answer field.

- Most numbers used in physics calculations are not exact, and answers obtained must reflect the proper use of significant digits.
  Possible solution: Machine-scorable open-ended questions can be used as a rigorous test of the proper use of significant digits, but that is not the intention here. In most questions, it will be obvious how many digits are called for. In those questions where it is not obvious, allowance for variations will be made in the key.

- Multiple answers cannot be completely eliminated, as the *Data Booklet* is of three-digit accuracy, and the use of different constants or equations as starting points automatically gives final answers that can differ by two or three in the third digit.
  Possible solution: We find more multiple answers in the Structure of Matter unit than in any other. All such answers could be eliminated if a five digit *Data Booklet* were used. However, the use of three digit input data is customary in physics teaching. Consequently, answer keys must allow for multiple answers. On the other hand, the keys do not allow for answers generated by premature internal rounding.

- Answers expressed in scientific notation to three-digit accuracy really need six spaces in the answer field, three to accommodate the numerical factor, one for the sign of the exponent, and two for the exponent.
  Possible solution: Six-space answer fields might prove too difficult to use, and the mixing of two or three different answer fields in a seven or twelve question section is undesirable. Therefore, for questions whose full answers require the use of scientific notation, we will use the following format:

  The force is $b \times 10^{w}$ N when expressed in scientific notation.
  The value of b (or of w) is _____.

The items

The 15 items were originally asked in multiple-choice form on previous Physics 30 Diploma Examinations. The Item Information Sheet on page 12 shows the item difficulties of the individual questions as tested. When reading this table, bear in mind that the difficulties of easy questions are above 0.750, of average questions between 0.550 and 0.750, and of difficult questions are below 0.550. It is probable that all items will be more difficult when asked in machine-scorable open-ended form.

The items illustrate answers that are numbers expressed to both two and three significant digits. For answers such as 1.47×10^{-17}, some questions call for the 1.47, while others call for the 17 in the exponent.

Other items are included to illustrate the presence of two or more valid answers. All valid answers are included on the Item Information Sheet on page 12, with only the most common answer included on the answer sheet on page 18. In working out the answers, we have not rounded any intermediate answers. Explanations of the allowed variations in the answers are found on pages 13 to 17.

Using the items

The items can be used as review sheets for physics content, or as practice items for the question format. It is not appropriate to use the complete set as a test, since the items were selected to illustrate the use of significant digits, the presence of valid multiple answers, the use of scientific notation, and the recording of partial answers. The set does not constitute a selection of typical physics problems that can be used as a unit test in Electric and Magnetic Fields.

Field Tests in Physics 30

All field tests in Physics 30, starting in January 1990, will contain machine-scorable open-ended questions. The instruction page used in these field tests is shown on page 4. Teachers are encouraged to share the contents of this document with their students before the field tests are administered. The form in which machine-scored open-ended questions appear on future Diploma Examinations largely depends on the results of the 1990 field tests.

SAMPLE INSTRUCTION SHEET (FOR MACHINE-SCORABLE OPEN-ENDED QUESTIONS)

INSTRUCTIONS

There are five machine-scored open-ended questions each with a value of 1 mark in this section of the test. All numbers used in the questions are to be considered as the results of measurements.

Read each question carefully.

Solve each question and write your answer to the appropriate number of significant figures.

Transfer your answer to the appropriate box on the answer sheet provided. Darken one circle in each column as necessary in order to record the answer to the correct number of significant figures, as illustrated below. USE AN HB PENCIL ONLY.

Sample Questions and Solutions

1) If the angle of incidence is 47.3° and the angle of refraction is 28.3°, the index of refraction is _____.

$$n = \frac{\sin \theta_1}{\sin \theta_2}$$

$$n = \frac{\sin 47.3°}{\sin 28.3°} = 1.55$$

RECORD 1.55

2) A microwave of wavelength 11 cm has a frequency of b x 10^9 Hz. The value of b is _____.

$$f = c/\lambda$$

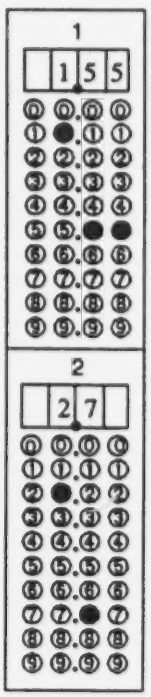
$$= (3.00 \times 10^8 \text{ m/s})/(0.11 \text{ m})$$

$$f = 2.727... \times 10^9 \text{ Hz}$$

RECORD 2.7

The answers 2.70, 2.72, and 2.73 will all be marked as incorrect, as the data given are to two significant figures only.

Answer Sheet



If you wish to change an answer, please erase your first mark completely.

WHEN YOU HAVE COMPLETED PART B, PLEASE PROCEED DIRECTLY TO PART C

SAMPLE MACHINE-SCORABLE OPEN-ENDED QUESTIONS

1. The number of excess electrons expressed in scientific notation, that must be collected on a sphere to give it a charge of -5.62×10^{6} C is $b \times 10^{w}$. The value of b is _____.

RECORD THE ANSWER ON THE ANSWER SHEET

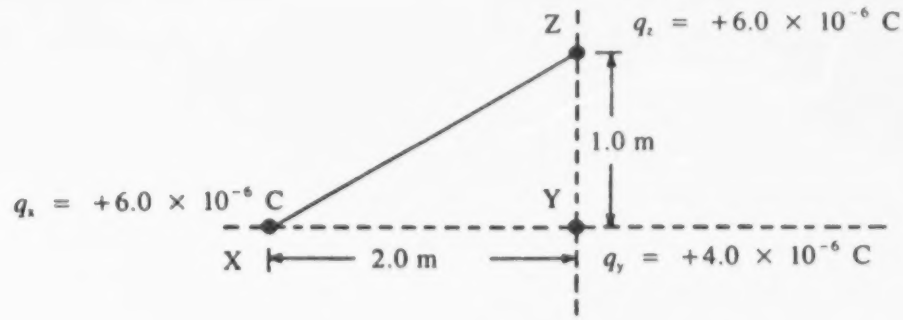
2. Two very small conducting spheres with equal radii have charges of 3.03×10^{-6} C and -6.09×10^{-6} C respectively. The spheres are touched together and then are separated to a distance of 5.00×10^{-2} m between their centres. The magnitude of the electric force on each sphere is _____ N.

RECORD THE ANSWER ON THE ANSWER SHEET

3. When two small clouds, each with a charge of 4.0 C, are separated by 3.0 km, the electrical force between the clouds, expressed in scientific notation, is $w \times 10^{b}$ N. The value of the exponent b is _____.

RECORD THE ANSWER ON THE ANSWER SHEET

Use the following information to answer question 4.



Positively charged particles X, Y, and Z form the vertices of a right triangle.

4. The magnitude of the force acting on Y due to X and Z is _____ N.

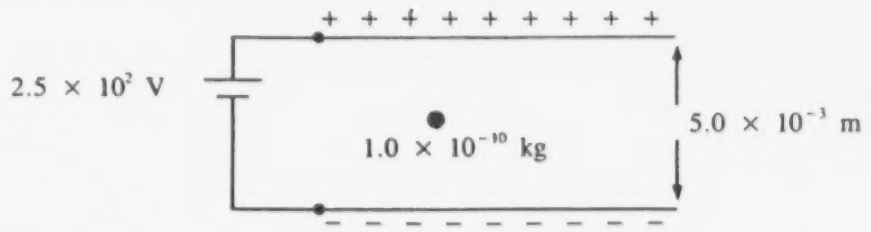
RECORD THE ANSWER ON THE ANSWER SHEET

5. The force on a positive charge of 3.6 x 10^{-3} C at a point in an electric field is 4.2 x 10^{-4} N. The magnitude of the electric field at that point is _____ V/m.

RECORD THE ANSWER ON THE ANSWER SHEET

Use the following information to answer question 6.

The charged particle has a mass of 1.1×10^{-10} kg and is suspended in an electric field between two horizontal plates that are 5.0×10^{-3} m apart. The potential difference between the plates is 2.5×10^{2} V.



6. The magnitude of the charge, expressed in scientific notation, is $b \times 10^{-W}$ C. The value of b is _____.

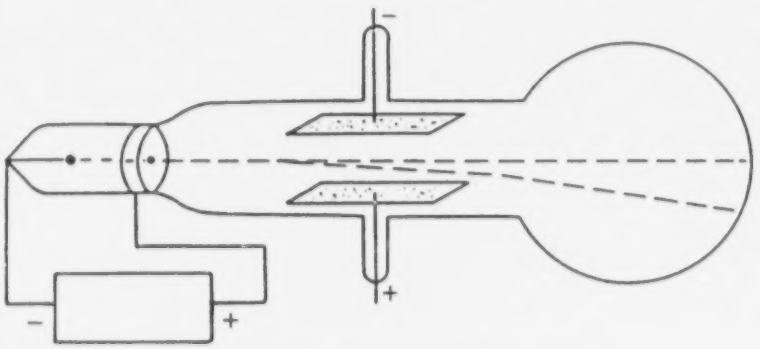
RECORD THE ANSWER ON THE ANSWER SHEET

7. Uranus has a mass of 8.80×10^{25} kg and a radius of 2.67×10^{7} m. The weight, expressed in scientific notation, of a 30.0 kg space probe that has landed on the planet's surface, is $b \times 10^{W}$ N. The value of b is _____.

RECORD THE ANSWER ON THE ANSWER SHEET

Use the following information to answer questions 8 and 9.

Cathode Ray Tube



Potential difference across deflector plates = 601 V
Deflector plate separation = 0.52 m
Deflector plate length = 0.12 m
Speed of cathode-ray particle = 0.017*c*

8. The particles are between the deflector plates for a time, expressed in scientific notation, of $b \times 10^{-w}$ s. The value of b is _____.

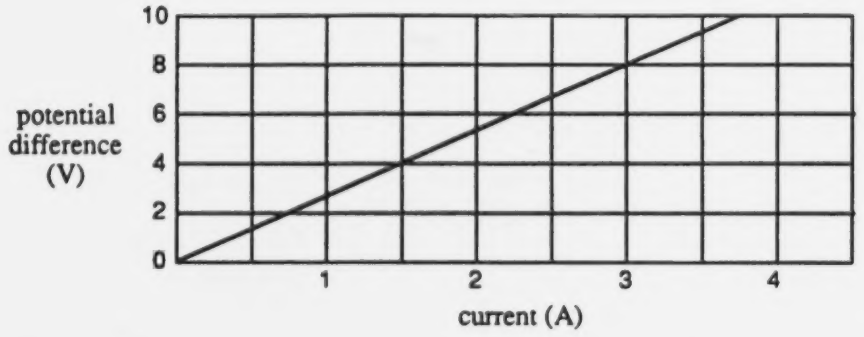
RECORD THE ANSWER ON THE ANSWER SHEET

9. When a cathode-ray particle is between the deflector plates, its vertical acceleration, expressed in scientific notation, is approximately $w \times 10^{b}$ m/s^2. The value of the exponent b is _____.

RECORD THE ANSWER ON THE ANSWER SHEET

Use the following information to answer question 10.

The graph below shows the potential difference across a fixed resistance for different values of the current in the resistance.



10. The resistance is _____ Ω.

RECORD THE ANSWER ON THE ANSWER SHEET

11. The potential difference across a 12 Ω resistor is 117 V. The power consumed by the resistor, expressed in scientific notation, is $b \times 10^{W}$ W. The value of b is _____.

RECORD THE ANSWER ON THE ANSWER SHEET

12. If an electron accelerates from rest for a distance of 4.12×10^{-3} m through a potential difference of 2.03×10^{3} V, the kinetic energy it gains, expressed in scientific notation, is $b \times 10^{-W}$ J. The value of b is _____.

RECORD THE ANSWER ON THE ANSWER SHEET

13. The Al^{3+} ion contains 13 protons and 14 neutrons. The charge-to-mass ratio (q/m) for this ion, expressed in scientific notation, is $b \times 10^{W}$ C/kg. The value of b is _____.

RECORD THE ANSWER ON THE ANSWER SHEET

14. Charged particles with varying speeds enter a region having an electric field $|\vec{E}|$ of unknown strength and a magnetic field B of strength 5.0 T. When v, B, and $|\vec{E}|$ are perpendicular to each other, the electric field, expressed in scientific notation, required to permit the undeflected passage of only the particles with speed 2.0×10^{5} m/s is $w \times 10^{b}$ N/C. The value of the exponent b is _____.

RECORD THE ANSWER ON THE ANSWER SHEET

15. A singly charged positive (1+) ion with a mass of 1.1×10^{-26} kg moves perpendicularly into a magnetic field of strength 1.2 T at a speed of 2.0×10^{5} m/s. The radius of the resulting orbit, expressed in scientific notation, is $b \times 10^{-w}$ m. The value of b is _____.

RECORD THE ANSWER ON THE ANSWER SHEET

ITEM INFORMATION SHEET

Item	Key	Multiple Choice Difficulty	Source
1	3.51	0.760	Jan'84 #12
2	8.42 8.43	0.341	Jan'86 #17
3	4.	0.837	June'86 #17
4	0.89	0.668	June'88 #17
5	0.12	0.899	Jan'88 #20
6	2.2	0.662	June'88 #21
7	2.46 2.47	0.783	Jan'88 #18
8	2.4	0.686	June'88 #40
9	14.	0.479	June'88 #42
10	2.7	0.931	June'85 #23
11	1.1*	0.882	June'85 #21
12	3.25	0.581	June'87 #20
13	1.06 1.07 1.08	0.520	new
14	6.	0.560	Jan'84 #18
15	1.1*	0.779	June'87 #25

Notes:

Questions 3, 9, and 14 will be marked correct with trailing zeros included, even though the answer is a whole number. The answers to questions 3 and 14 MUST be recorded in the SECOND column of the answer field.

*For explanation of these single answers refer to page 15 for question 11 and to page 17 for question 15.

SAMPLE SOLUTIONS TO QUESTIONS WITH MULTIPLE ANSWERS

Solution to question 2

$$q_1 = 3.03 \times 10^{-6} \text{ C}$$

$$q_2 = -6.09 \times 10^{-6} \text{ C}$$

Conservation of charge:

$$q = q_1 + q_2 = -3.06 \times 10^{-6} \text{ C}$$

Half the charge is on each sphere:

$$q_{1f} = q_{2f} = -1.53 \times 10^{-6} \text{ C}$$

Calculating the force of attraction:

$$F = kq_{1f}q_{2f}/r^2$$

$$= \frac{8.99 \times 10^9 \text{ N}\cdot\text{m}^2 \ (-1.53 \times 10^{-6} \text{ C})(-1.53 \times 10^{-6} \text{ C})}{(5.00 \times 10^{-2} \text{ m})^2}$$

$$F = 8.418 \text{ N} = 8.42 \text{ N}$$

Note: If $k = 9 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$ is used to calculate the force of attraction, then an answer $F = 8.43$ N is obtained.

Bubble 8.42 or 8.43

Note: a bubble of 8.4 or 8.40 is incorrect.

Solution to question 7

On Earth $W = mg$

$= (30.0\ \text{kg})(9.81\ \text{N/kg})$

$W = 294.3\ \text{N}$

On Uranus $F_u = GmM_u/r_u^2$

$Gm = F_u r_u^2/M_u = F_e r_e^2/M_e$

$F_u = F_e r_e^2 M_u/(r_u^2 M_e)$

$$= 294.3\ \text{N} \left(\frac{6.37 \times 10^6\ \text{m}}{2.67 \times 10^7\ \text{m}}\right)^2 \left(\frac{8.80 \times 10^{25}\ \text{kg}}{5.98 \times 10^{24}\ \text{kg}}\right)$$

$F_u = 246.51\ \text{N} = 247\ \text{N} = 2.47 \times 10^2\ \text{N}$

Notes: If $W = 294$ N is used as the calculated weight of the probe on Earth, then an answer $F_u = 246.3$ N is obtained.

If $F_u = GmM_u/r_u^2$ is used directly, an answer of $F = 247.0$ N is obtained.

Bubble 2.47 or 2.46

Solution to question 11

$$I = V/R$$

$$= 117 \text{ V}/12 \ \Omega$$

$$I = 9.75 \text{ A}$$

$$P = I^2R$$

$$= (9.75 \text{ A})^2(12 \ \Omega)$$

$$P = 1.1 \times 10^3 \text{ W}$$

Notes: Using a current of 9.8 A produces an answer of 1.2×10^3 W. This answer is not acceptable as it involves a calculation based on a prematurely rounded value for current.

Power may be calculated directly using the equation $P = V^2/R$ producing an answer of $P = 1.1 \times 10^3$ W.

Bubble 1.1

Solution to question 13

Method 1

$$q/m = [3(1.60 \times 10^{-19}\ C)]/[27(1.67 \times 10^{-27}\ kg)]$$

$$q/m = 1.06 \times 10^{7}\ C/kg$$

Bubble 1.06

Method 2

$$q/m\ (\text{hydrogen}) = 1.60 \times 10^{-19}\ C/1.67 \times 10^{-27}\ kg$$

$$q/m\ (\text{hydrogen}) = 9.58 \times 10^{7}\ C/kg$$

$$q/m\ (\text{aluminum}) = [q/m\ (\text{hydrogen})] \left[\frac{\text{charge ratio } (Al^{3+}/H^{+})}{\text{mass ratio } (Al^{3+}/H^{+})}\right]$$

$$= (9.58 \times 10^{7}\ C/kg) \left[\frac{3e/e}{(26.98\ g/mol)/(1.01\ g/mol)}\right]$$

$$q/m\ (\text{aluminum}) = 1.08 \times 10^{7}\ C/kg$$

Bubble 1.08

Method 3

$$\text{mass } (Al^{3+}) = (26.98\ g/mol)/(6.02 \times 10^{23}\ ions/mol)$$

$$= 4.48 \times 10^{-23}\ g$$

$$= 4.48 \times 10^{-26}\ kg$$

$$q/m\ (Al^{3+}) = 3(1.60 \times 10^{-19}\ C)/(4.48 \times 10^{-26}\ kg)$$

$$q/m\ (Al^{3+}) = 1.07 \times 10^{7}\ C/kg$$

Bubble 1.07

All three methods are equally valid.

Solution to question 15

$$r = mv/qB$$

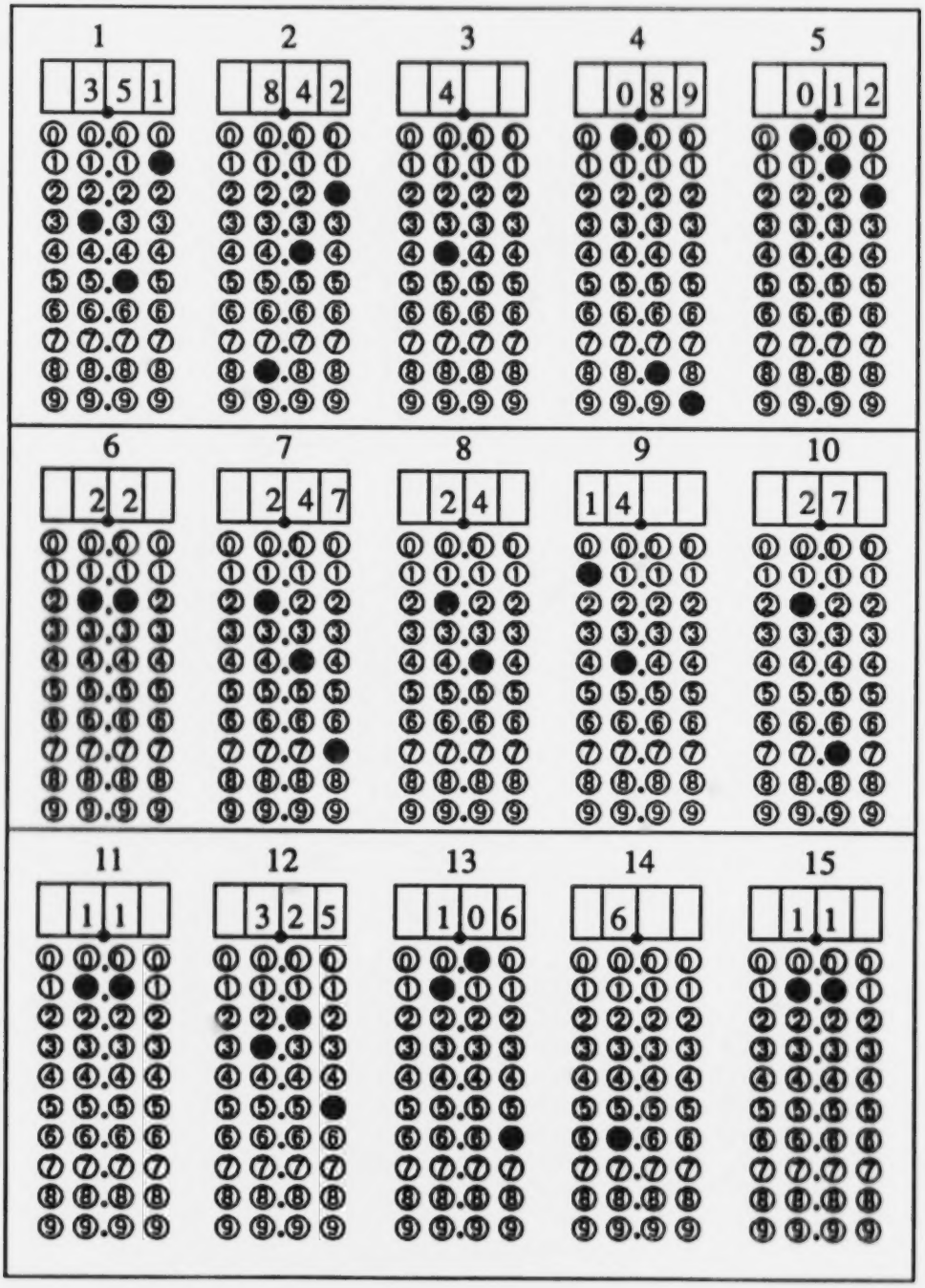
$$= \frac{(1.1 \times 10^{-26}\ \text{kg})(2.0 \times 10^{5}\ \text{m/s})}{(1.60 \times 10^{-19}\ \text{kg})(1.2\ \text{T})}$$

$$r = 1.1 \times 10^{-2}\ \text{m}$$

Note: If magnetic force is calculated first ($F = qvB = 3.84 \times 10^{-13}$ N), followed by radius ($R = mv^2/F$), an answer of 1.2×10^{-2} m can be obtained if force F is rounded to 3.8×10^{-13} N before proceeding to the next step in the calculation. This is not allowed since numerical answers are only to be rounded once, at the end of the question.

Bubble 1.1

ANSWER SHEET WITH SOLUTIONS DISPLAYED



SAMPLE ANSWER SHEET, BLANK FOR STUDENT USE